A Simple PANFI (SPANFI) – Concept and Implementation

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Abstract

In this paper a simple precision automatic noise figure indicator (SPANFI) for amateur use is described. With this equipment the measurement of gain and noise figure e.g. of preamplifiers for EME application is possible at the same time where measurement update rate is sufficient to allow real-time tuning of the device under test. Accuracy of the instrument is sufficient to measure noise figures below 1 dB in the frequency range up to 500 MHz by the use of noise generators of known excess noise ratio (ENR). As in commercial equipment higher frequency application is possible by use of external mixers and depends then only on the frequency range of the noise generator.

1. Introduction

In EME application the receiver performance is mainly determined – besides the antenna system – by the noise figure and gain of the first amplifier following the antenna. That holds also for new digital modes and the topic is therefore of interest for every EME enthusiast still today. Commercial equipment for measurement of noise figure and gain, like the famous HP8970 [5], is nearly not available on the surplus market and if so the price is out of reach for the average amateur. On the other hand solid state noise generators with calibrated ENR values which are a prerequisite for accurate and repeatable noise figure measurement results are available on nearly every ham flea market at affordable prices.

Different PANFIs where described in amateur radio literature in the past either as stand-alone equipment [1], [2] or as add-on for existing spectrum analyzers [3]. All these designs are some years old and thus this paper aims at a more modern and at the same time simpler solution with at least the same accuracy.

The described PANFI is based on the well-known y-factor approach and here signal processing, control of noise source, A/D converter and display is performed by a small microcontroller. Also the RF part of the instrument is as simple as possible and makes use of standard modern semiconductor parts and an external RF bandpass filter for the frequency of interest without mixing to intermediate frequencies.

The outline of the paper is as follows. In the next chapter some theory providing the basics of the measurement principle is given. Analysis of the logarithmic detector as key element of the PANFI follows the ideas of [6]. Chapter 3 describes the implementation including details on hardware and software as well as on alignment. Measurement examples are given in chapter 4 and show the appropriateness of the implemented solution. Conclusions and some ideas on further enhancements are given in the last chapter.

2. Theory of operation

The basic equation which is evaluated in the described simple precision noise figure indicator is given by

$$F = ENR - 10 \cdot \log10(y-1) \qquad (1)$$

where F is the noise figure in dB, ENR = 10*log10((T_hot-T_cold)/To) is the excess noise ratio of the noise source in dB connected to the input of the device under test (D.U.T.) and

$$y = Pon/Poff \quad (2)$$

is the ratio of average noise powers Pon and Poff at the output of the D.U.T. delivered to the indicator. Pon corresponds to the case where the noise generator at the input of the D.U.T. is switched “on” (delivering noise temperature T_hot) whereas Poff is the D.U.T.s output power when the noise generator at the input is switched off (delivering noise temperature T_cold).

Eq. (1) is based on several simplifications:

1. The ambient temperature during the measurement is equal to the reference temperature To = 290 K (= 17 °C) and corresponds to the cold temperature of the noise source: To = T_cold.
2. The reflection coefficient of the noise source is zero for “on” as well as for “off” state. Thus there is no gain error apparent, see [2].
3. The noise figure of the indicator which measures the y factor is zero. Thus noise figure of the indicator in terms of a cascaded second stage contribution can be neglected.

More details and the derivation of Eq. (1) can be found in [2] and [5].

In this paper we will emphasise on how to measure the y factor. As given in Eq. (2) it is the ratio of two power values which are both considered as originated from random motion of charge carriers, e.g. electrons in electrical conductors, caused by thermal agitation. This noise is called thermal noise, Nyquist noise, or Johnson noise [11]. The number of electrons is large and their motions are independent. Therefore, the variation in the rate of current flow or corresponding voltage across a resistor takes on a Gaussian probability density function (PDF) in accordance with the central limit theorem from statistics. Whereas the Gaussian PDF holds directly for thermal noise voltages in base-band the situation for bandpassed noise is a little bit more complicated: using the in-phase (I) and quadrature (Q) representation of a bandpass signal, for both independent I- and Q-components the Gaussian PDF holds. The envelope or magnitude of the noise signal is given by

$$v_{env} = \sqrt{v_I^{\,2} + v_Q^{\,2}} \qquad (3)$$

where v_I is the in-phase and v_Q is the quadrature Gaussian distributed component of the noise. The probability density function of v_{env} is no longer Gaussian distributed but its PDF is given by a Rayleigh distribution where

$$PDF(v_{env}) = \frac{v_{env}}{s^2} \exp\left(-\frac{1}{2} \left(\frac{v_{env}}{s} \right)^2 \right) \quad (4)$$

and σ^2 is the variance of the envelope voltage.

Due to dynamic range reasons e.g. in spectrum analyzers as well as in this SPANFI a logarithmic detector is used. Thus the Rayleigh PDF according Eq. (4) will change if we apply logarithmic processing to the envelope voltage. The log amplification acts as a compressor for large noise peaks; a peak of ten times the average level is only 10 dB higher. Instantaneous near-zero envelopes, on the other hand, contain no power but are expanded toward negative infinity decibels. Fig. 1 out of [6] shows a Rayleigh PDF according to Eq. (4). In Fig. 2 taken from [6] the PDF of the envelope after log processing is depicted.

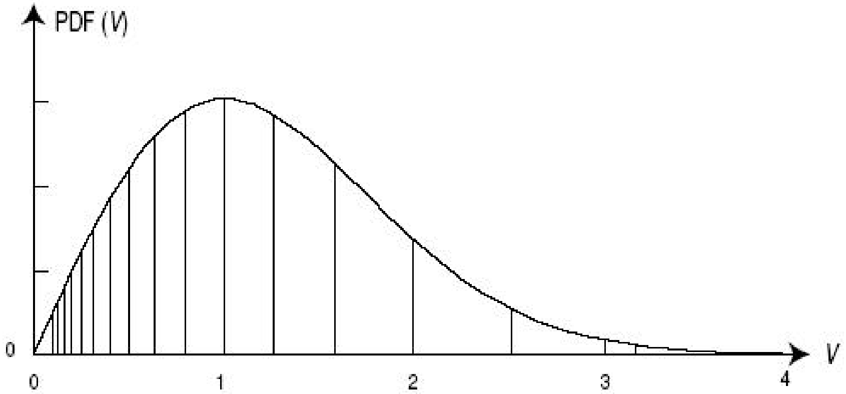

Fig. 1: Rayleigh distribution of noise envelope voltage taken from [6].

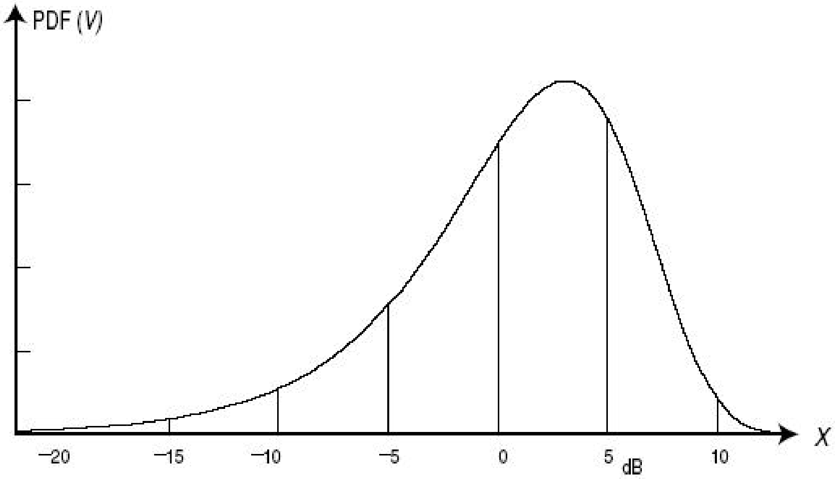

Fig. 2: Distribution of noise envelope voltage after log processing taken from [6].

At the end we are interested in the average power coming from a series of instantaneous voltage values following the PDF according to Fig. 2. By averaging instantaneous power values, each calculated as a squared voltage value following the distribution in Fig. 2 divided by a resistor R the standard deviation of the result will decrease as the number N of instantaneous power measurements is increased corresponding to the following equation from [6]:

$$s_m = 5.57dB \big/ \sqrt{N} \qquad (5).$$

In other words: if we take 10000 instantaneous noise power measurements where the results are given in dBm and average these values the average power of the noise can be determined with a standard deviation of less than 0.06 dB. The underestimation of the absolute value of our result e.g. due to averaging of log values instead of log processing of the average is not important due to the fact that we are dealing with noise power ratios as in Eq. (2) or differences of log values and that this kind of constant error is canceled when subtracting the two log values.

Real world log amplifiers suffer from a limited range: lower limit is given by noise floor and upper limit is determined by clipping. In Fig. 3 the log response of an AD8307 [7] at three different frequencies is shown. Below an input power of approx. –65 dBm noise is dominating and above + 10 dBm clipping can be seen.

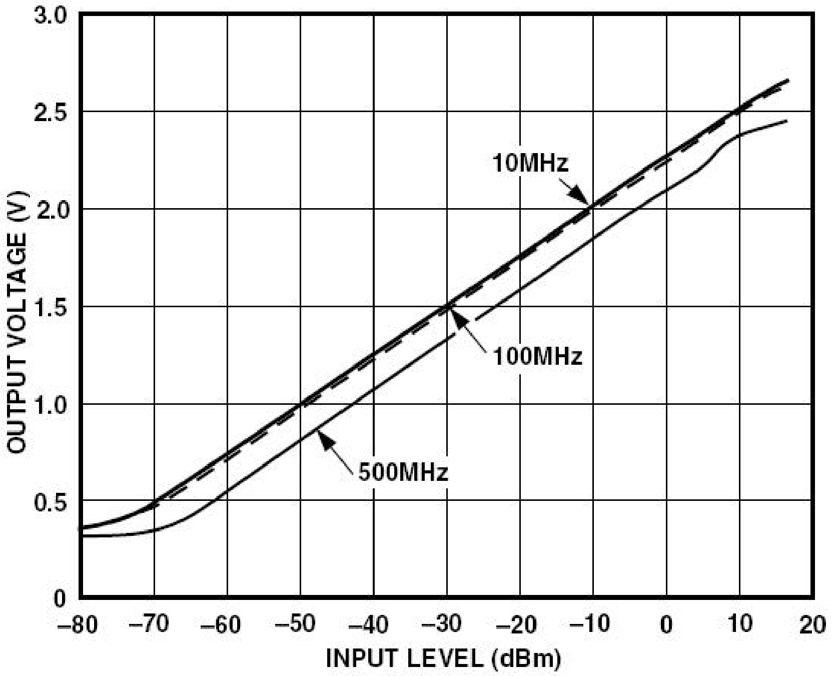

Fig. 3: Output voltage of the AD8307 at three different frequencies.

To hold the error in average noise power measurement below 0.1 dB due to these clipping effects the average noise power to be measured should be kept > 14 dB above the lower range limit of the log amplifier – in our AD8307 example > - 51 dBm. On the other hand to keep clipping effect error below 0.1 dB at the higher limit of the log amplifier range average noise power should be kept at least 7 dB below that limit – in our AD8307 example < + 3dBm [6].
At this point we are able to measure the y-factor of noise powers from Eq.(2) by using a log amplifier and averaging its instantaneous results to the required standard deviation of the result.
As mentioned before the derivation of noise power measurement was done for bandwidth limited noise. That bandpass limitation has to be chosen according different criteria:

1. The bandwidth should be small enough to allow a sufficient frequency resolution because we would like to have the noise figure result as a function of frequency.
2. The bandwidth should be as large as possible to keep additional amplification in front of the log detector/amplifier low. Remember that the available noise power is proportional to the bandwidth: Pn = kTB (k: Boltzmann constant, T: temperature, B: bandwidth), e.g. Pn = -104 dBm at room temperature in 10 MHz bandwidth.
3. We need statistical independent instantaneous noise power measurements to be averaged. As a rule of thumb the time difference between two successive instantaneous power measurements should be larger than 1/B to fulfil that demand. At the same time we would like to have a fast measurement repetition time to allow real-time alignment of the D.U.T., e.g. a preamplifier. In case of a small bandwidth we would require a long time between successive instantaneous power measurements to have them all statistical independent from each other and averaging of many values would be a lengthy task. Therefore we should allow the bandwidth to be as wide as possible.

3. Implementation

3.1 General concept

In this chapter the implementation of a simple precision automatic noise figure indicator based on the theory introduced in the previous chapter is described in detail. Fig. 4 shows the main building blocks and the principle measurement set-up. A device under test is fed at its input by a noise generator of known ENR value. The D.U.T.s output is followed by a low noise broadband amplifier to bring the noise level to a value which can be processed later by the log amplifier / detector. In front of this stage a bandpass filter is inserted to allow frequency dependent measurements. Whereas it is desirable to use variable bandpass filtering here also fixed bandpass filtering e.g. for 144 MHz or 430 MHz could also be used. After log amplification / detection the result is A-to-D converted and the result is further processed in a micro-controller. The micro-controller performs averaging of instantaneous power values as well as control of the noise generator by means of switching it on and off. On the basis of the measured y-factor Eq. (1) is evaluated by a look-up table. To allow also gain measurements the noise power without the D.U.T. is measured during a calibration phase when switching on the SPANFI. Thus the actual gain is simply given by the difference of the log noise power measured with D.U.T. and without each when the noise generator is switched on.

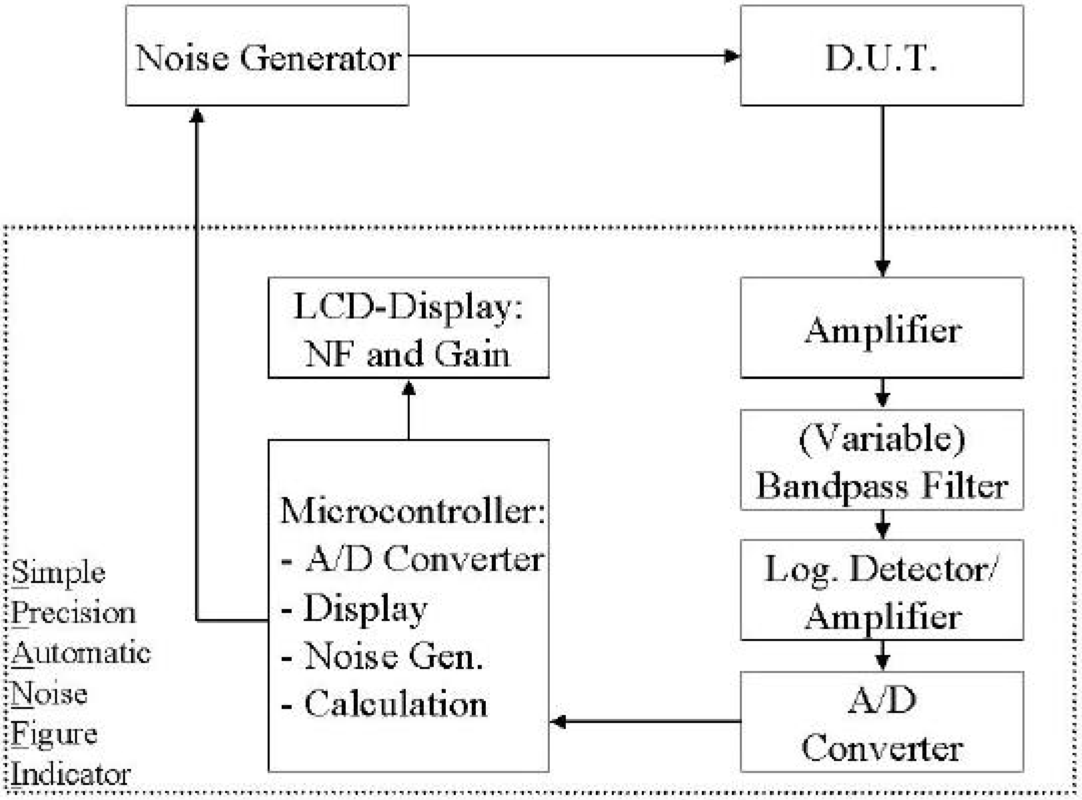

Fig. 4: Main building blocks of a SPANFI and measurement set-up.

3.2 Hardware

According to Fig. 4 a hardware to realise the SPANFI was developed. In Fig. 5 the circuit diagram of RF part of the SPANFI is depicted. The input of the circuit is connected to the output of the D.U.T. and consists of a three stage broadband amplifier each stage build of an ERA-3 with was chosen as a compromise of gain and noise figure. Between the second and the third stage an external variable bandpass filter is inserted which determines centre frequency and bandwidth of the measurement. Taking into account the insertion loss of the bandpass filter the overall gain of this amplification is about 65 dB. At the output of the third stage an AD8307 as log amplifier / detector is used. Its input is terminated with a resistor of 52 Ohms. In the original prototype realisation a Texscan/Trilithic variable octave bandpass filter either 5VF125/250-2-50-CC (125 MHz …250 MHz) or 5VF250/500-2-50-CC (250 MHz … 500 MHz) is used. The bandwidth of these filters is a constant fraction of 2% of the centre frequency, e.g. 2.5 MHz @ 125 MHz or 10 MHz @ 500 MHz centre frequency.

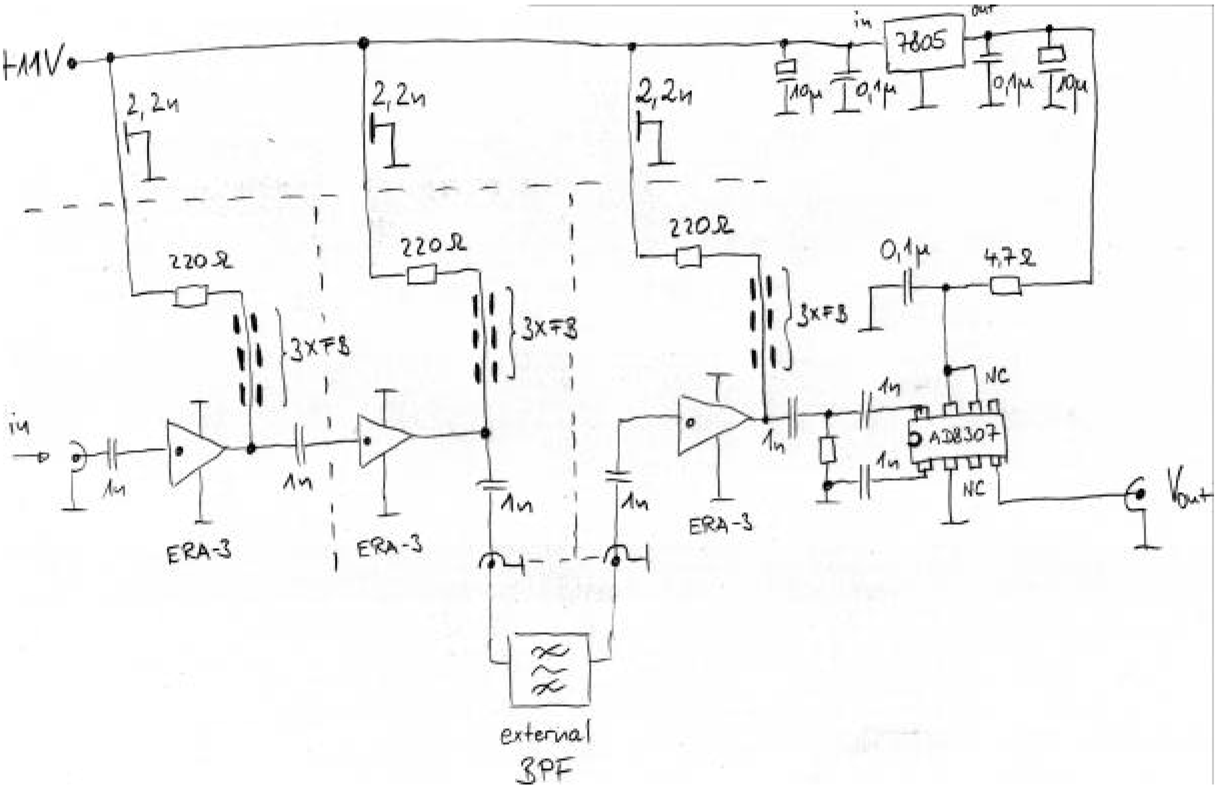

Fig. 5: RF part of the SPANFI.

In Fig. 6 the RF part construction as “dead-bug” style within a shielded box is shown.

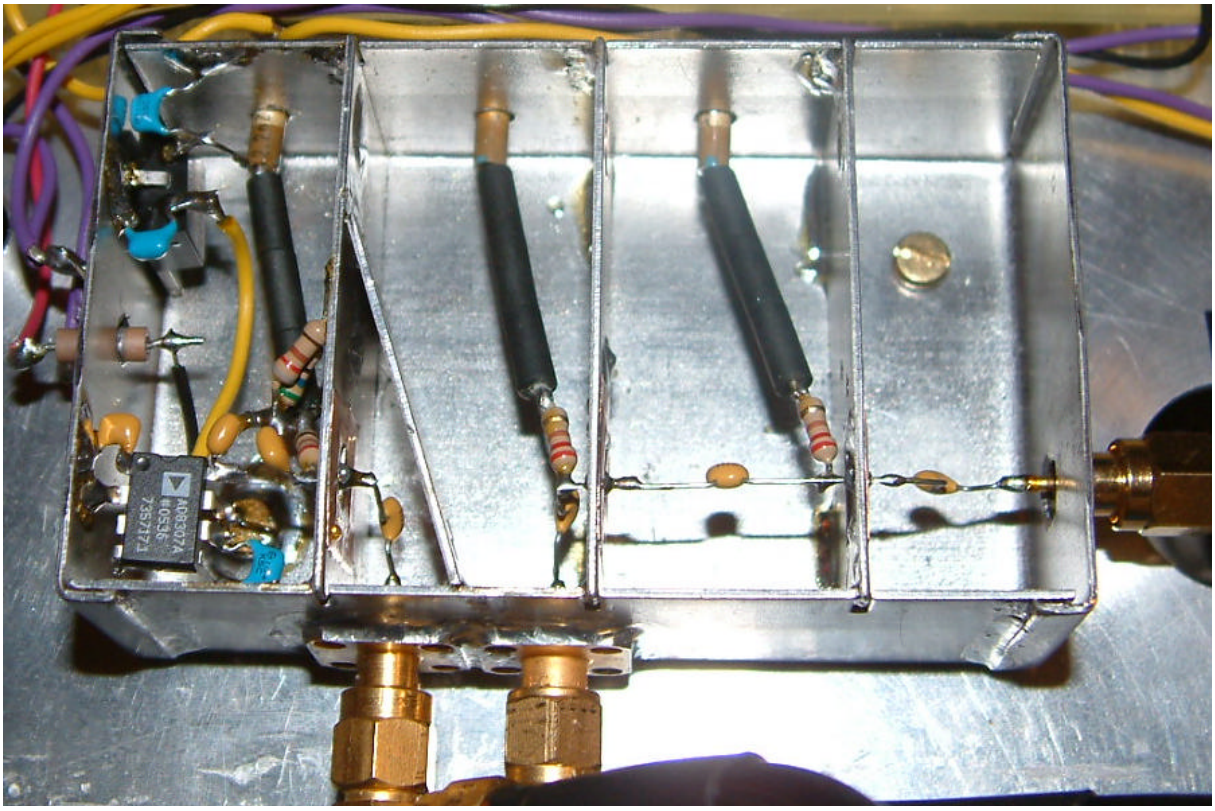

Fig. 6: “dead-bug” style construction of RF part in shielded box.

The output voltage of the RF part in Fig. 5 is fed without any buffering into the A/D converter input of the digital part of the SPANFI depicted in Fig. 7. The A/D converter is a 12 Bit resolution LTC1860 which allows fast conversion of up to 250 ksps. Thus a fast measurement repetition is ensured. With the reference voltage of 4.095 V derived from the supply voltage a resolution of 1 mV is given. Together with logarithmic slope of typical 25 mV/dB of the AD8307 that results in 0.04 dB resolution for the least significant bit of the digital result. The main part of the digital circuit is an Atmel controller AT90S2313 clocked at 10 MHz which generates chip select and clock signals for the LTC1860 and switches the noise generator via an opto-coupler CNY-17 which can deliver a current of typical 20 mA for commercial noise generators like the Ailtech 7615 or HP456b. Also processing – described in further detail in the software chapter – as well as result display by means of two LEDs and a two-line LCD module is performed by this controller. Depending on the switch – “ENR1” and “ENR2” – two different ENR values for the noise generator are provided in the software. As mentioned an Ailtech 7615 with a nominal ENR of 15 dB is used. To realise a nominal ENR of 5dB the Ailtech 7615 together with a precision attenuator of 10 dB at its output is used. The resulting noise generator is of advantage due to an enhanced RF reflection behaviour, see [2], as well as a lower required dynamic range of the log amplifier in comparison to high value ENRs. Fig. 8 shows the realisation.

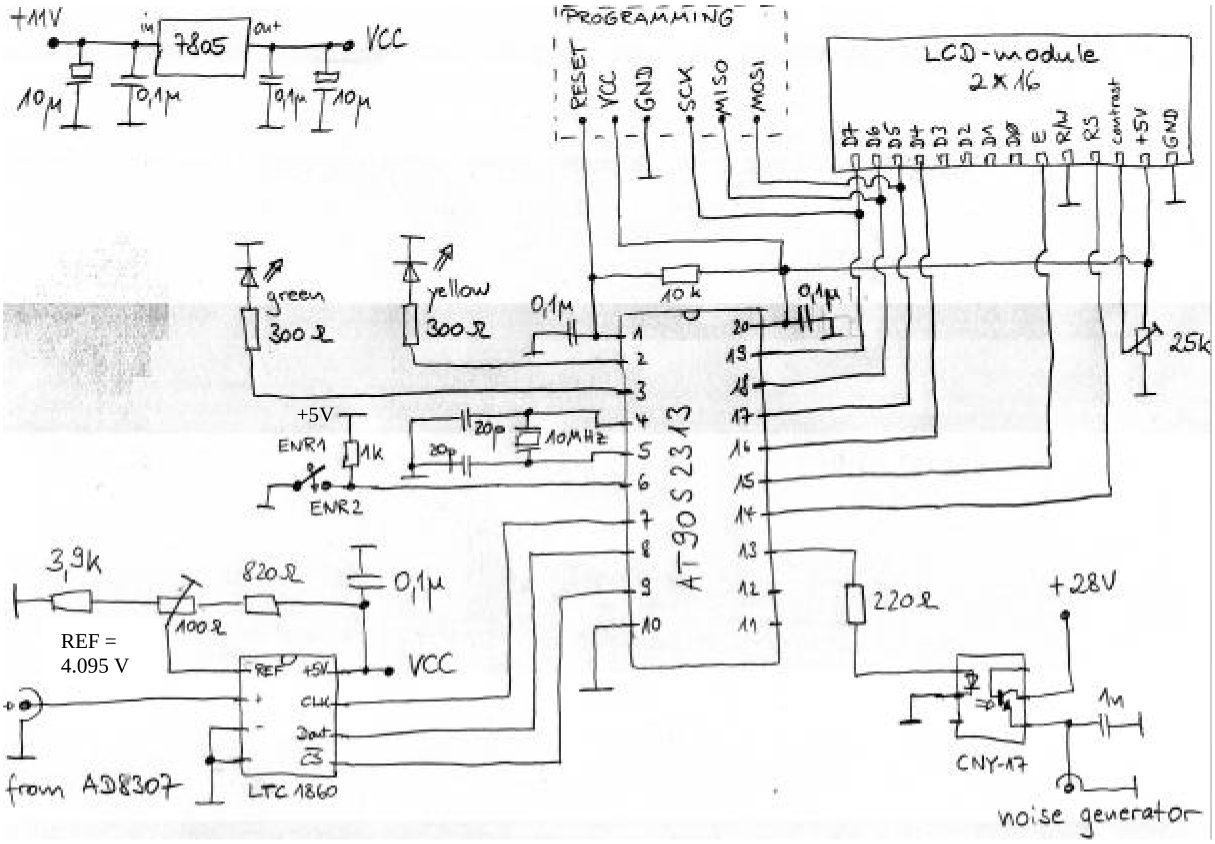

Fig. 7: Circuit diagram of the digital part of the SPANFI.

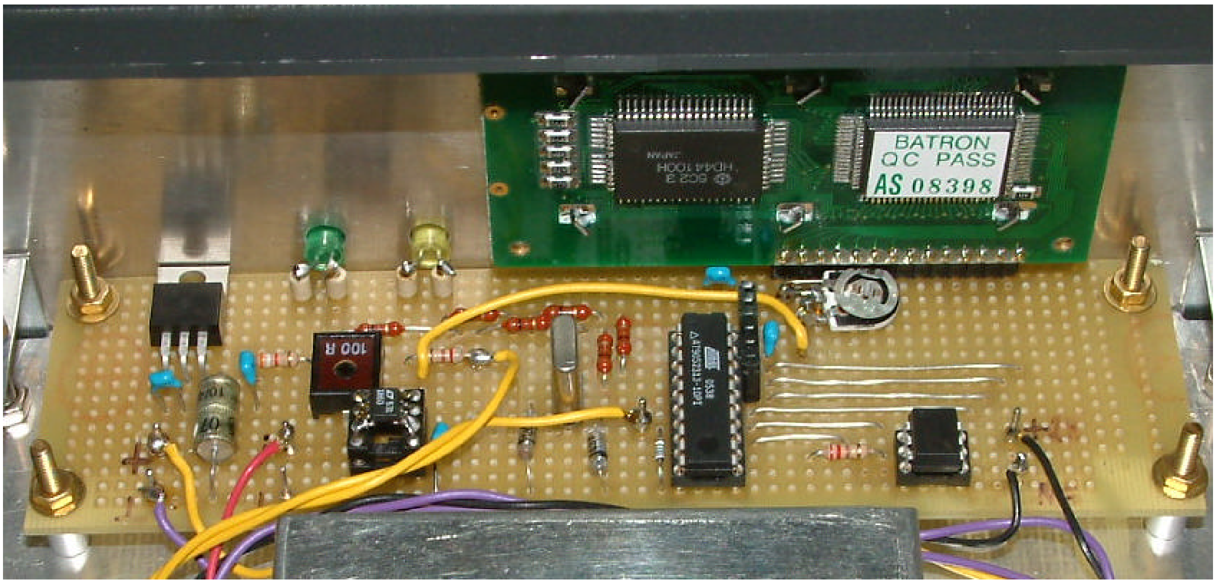

Fig. 8: Realisation of the digital part of the SPANFI.

The last building block is the power supply given in Fig. 9. There is nothing special besides the series Zener diode – here a ZX10 - in the 28 V path in front of the variable voltage regulator µA78MG. That Zener diode together with the 10 kOhm resistor to ground limits the maximal voltage for the regulator input. Realisation of that part of the SPANFI is given in Fig. 10.

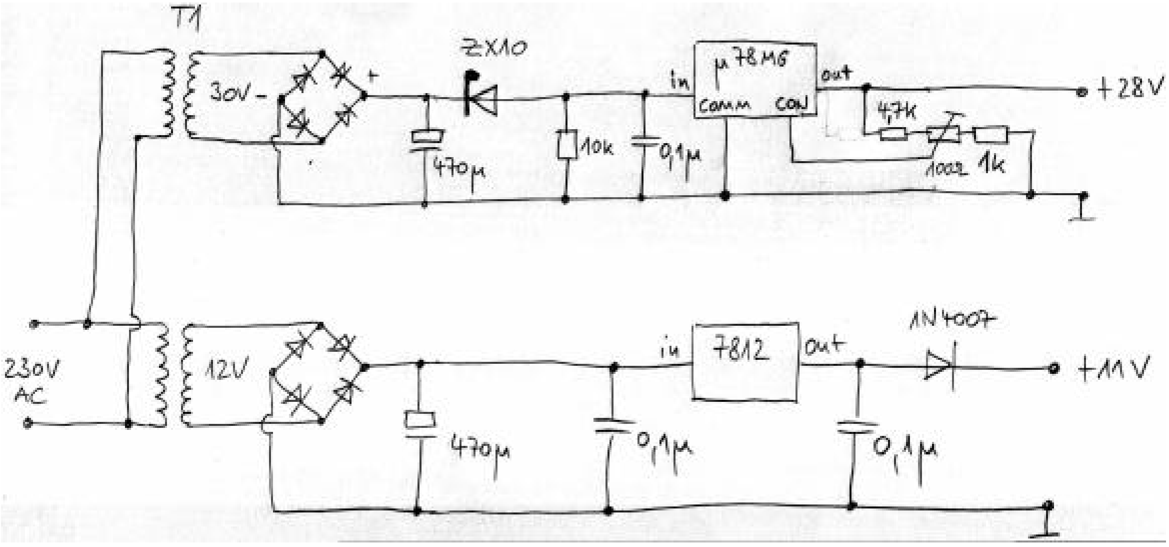

Fig. 9: Power supply circuit of the SPANFI

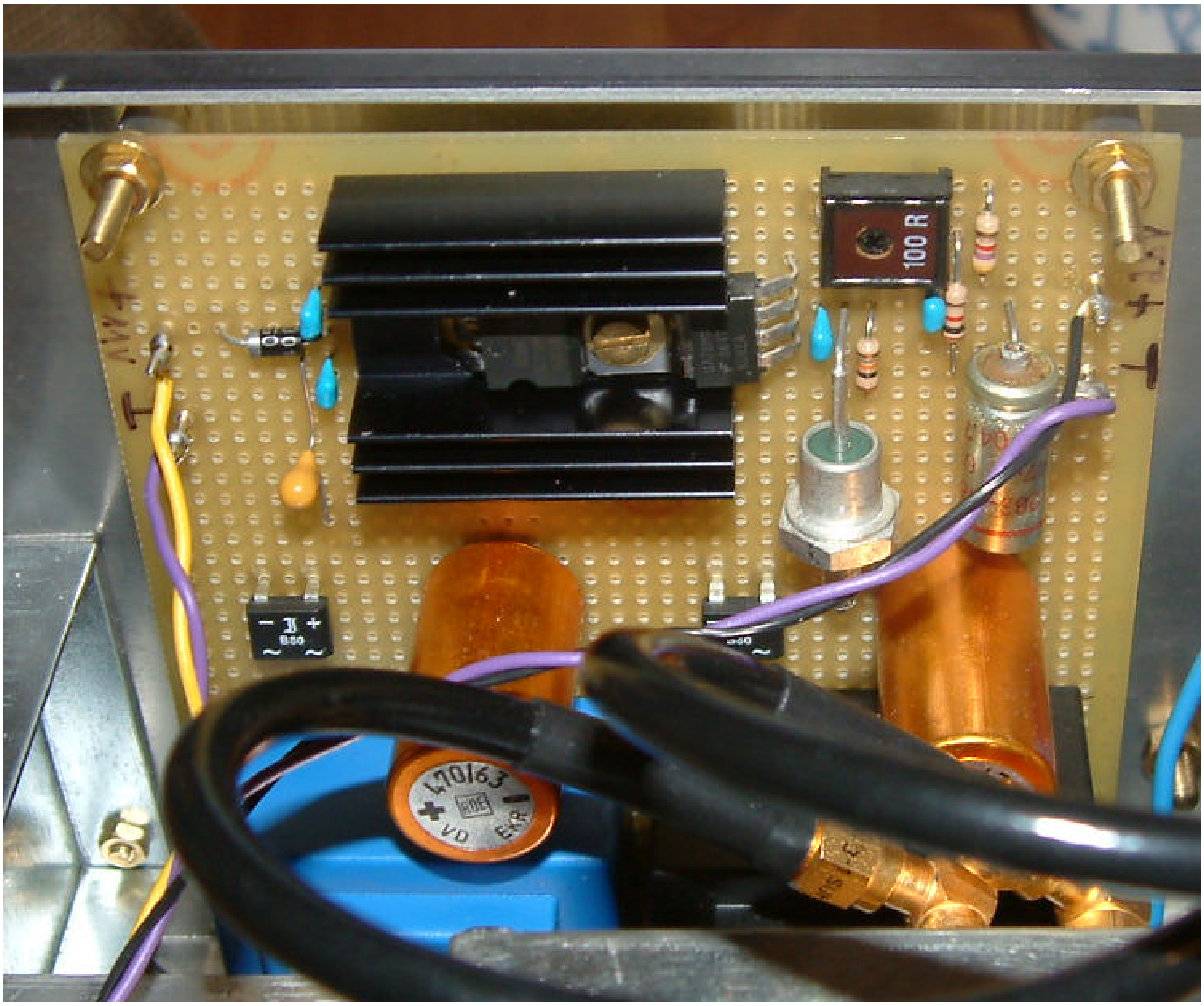
Fig. 10: Realisation of power supply.

3.3 Software

As stated in the previous chapter a key part of the SPANFI is an Atmel micro-controller AT90S2313. As development environment BASCOM-AVR-BASIC was used [10]. Besides simple programming in Basic language the demo version of this compiler - which is sufficient to write the complete code given in annex - is for free.

The mains on/off switch has two positions. Each of the two on positions assumes a different ENR value for the used noise generator: depending on the choice when switching on two different measurement ranges are possible for noise figure measurement are possible (see Table 1).

In a calibration phase the noise power of the noise generator directly connected to SPANFI's input without D.U.T. is measured. This value is used in the measurement loop to derive the gain of the D.U.T. After that initialization and calibration a continuously repeating measurement loop is started where the Y factor is derived as a difference of log values of averaged instantaneous power values. According the Y factor measured in each measurement cycle a look up table value for the noise figure is displayed. The implemented look up tables represent Eq. (1) as well as some "software" tuning regarding variation of the logarithmic slope of the AD8307 which is typically 25 mV/dB. Due to memory reasons the two look up tables are realized as tables of bytes.

In Table 1 the main properties of the SPANFI with the actual software implementation are given.

	NF range 1	NF range 2
ENR of noise generator	15.53 dB	5.93 dB
Number of averaged instantaneous power measurements	N = 4096	N = 8192
Standard deviation of averaged power measurements, see Eq. (5)	σ_m = 0.087 dB	σ_m = 0.062 dB
Resolution of power measurement (25.55 mV/dB measured slope of AD8307 and 1 mV resolution of A-to-D conversion)	0.1566 dB/4mV (4mV stepsize is evaluated)	0.039 dB/mV (1mV stepsize is evaluated)
Noise figure range	0 … 21 dB	0.04 … 2.51 dB
Measurement update rate / duration of one measurement cycle	~ 3 sec.	~ 6 sec.

Table 1: Main properties of SPANFI.

It is recommended to measure the actual log slope of the AD8307 when building this SPANFI, e.g. by means of a signal generator and a precise attenuator. Then individual look up table can be calculated with the measured slope, the known ENR and Eq.(1).

4. Measurement examples

In Fig. 11 the parts for different measurement examples are depicted.

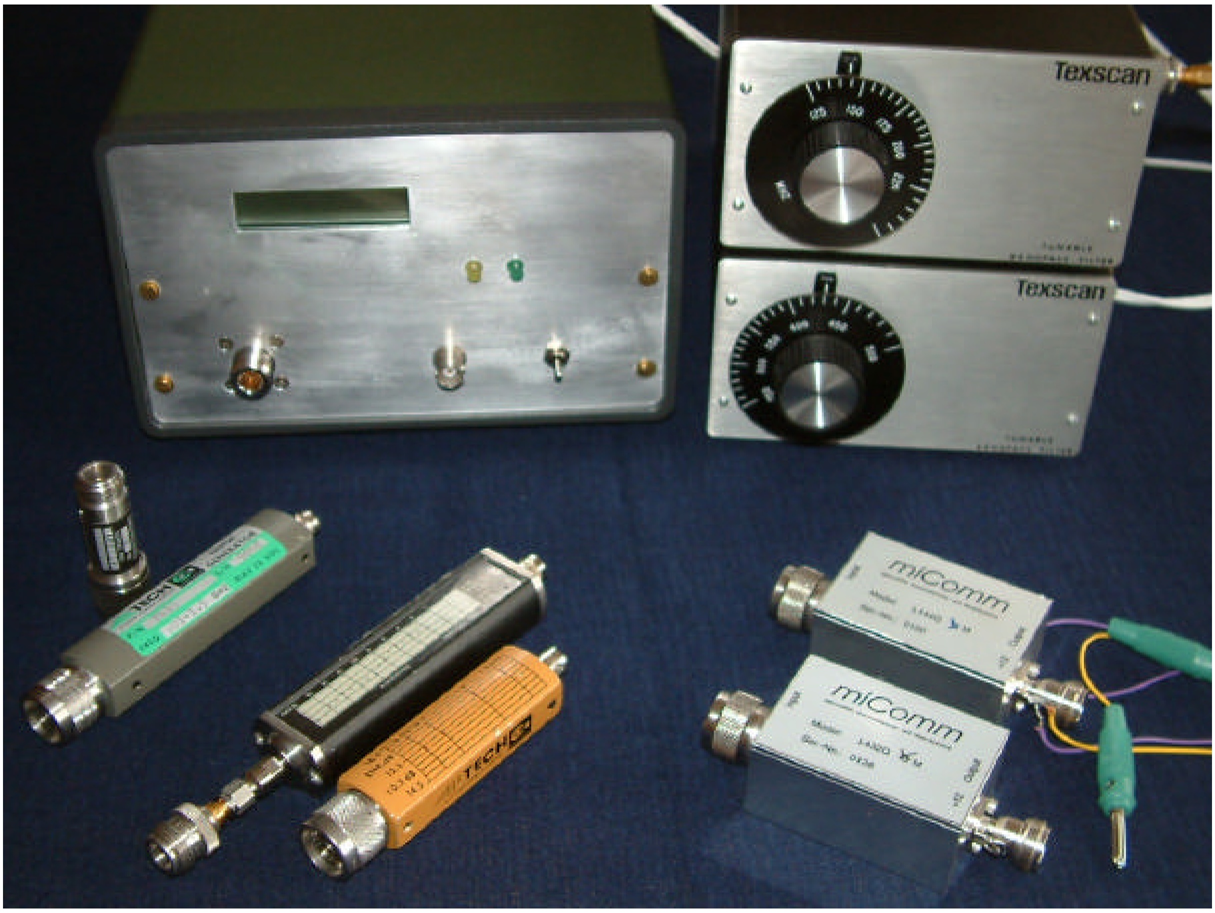

Fig. 11: SPANFI, variable octave bandpass filters, miComm LNAs (as D.U.T.s), different noise generators and fixed attenuator.

In a first measurement the noise figure of the SPANFI itself was measured as a function of frequency for the three different noise sources shown in Fig. 11. The result is given in Fig. 12.

It should be noted that even for the same nominal ENR value of 15.5 dB significant differences between the three noise generators are obtained. The upper two curves are for two different Ailtech 7615 noise generators whereas the lower curves holds for a HP346b source.

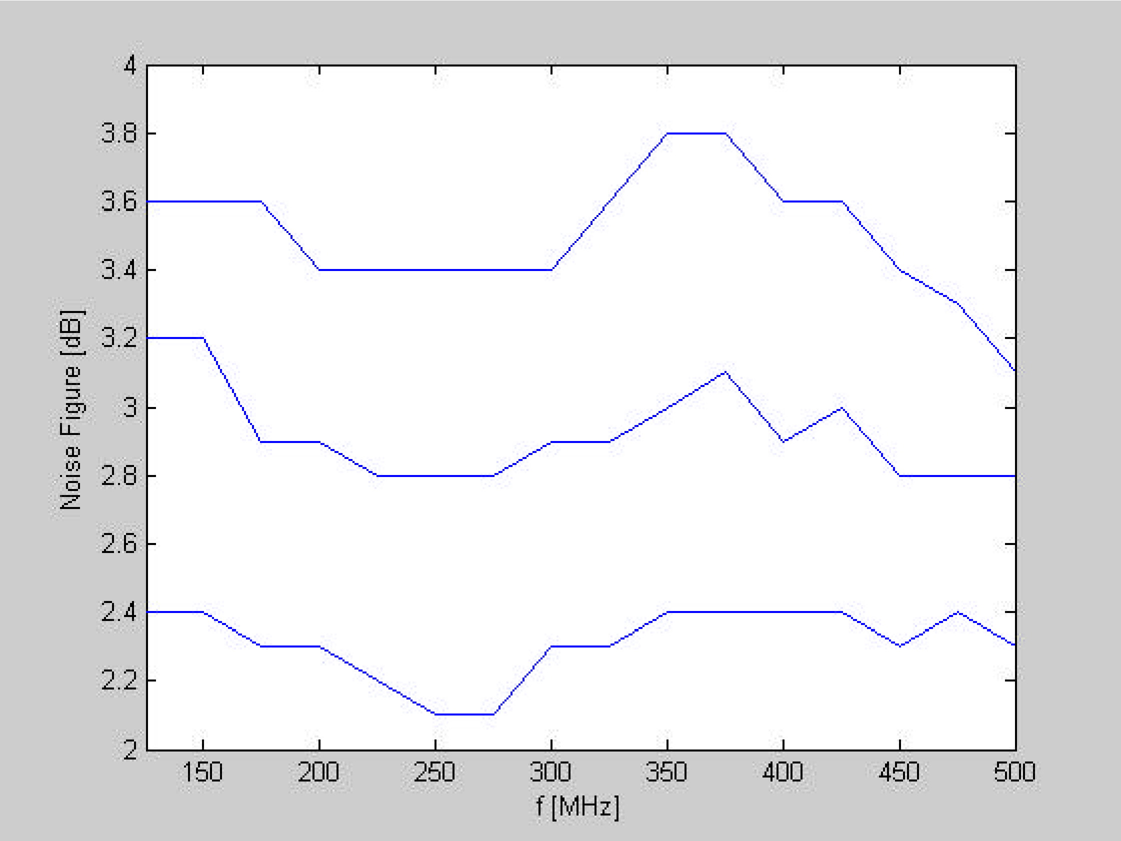

Fig. 12: Noise figure of the SPANFI as function of frequency for three different noise generators of nominal ENR = 15.5 dB: upper two curves for two different Ailtech 7615, lower curve for HP346b.

Taking into account the typical noise figure of 3.5 dB @ 2 GHz for the ERA-3 and the calibration uncertainty of the noise sources – e.g. for the HP346b that is +/- 0.3 dB - the results seem to be reasonable.

In a second measurement example two commercial low noise amplifiers [9] were measured and compared against the available measurement protocol. The results are given in Table 2. Again results for gain and noise figure seem very reasonable and differences regarding noise figure lay well within calibration uncertainty of the noise generator.

D.U.T.	Measurement results with SPANFI, ENR = 5.93 dB (Ailtech 7615 #9282 plus Weinschel 9,6 dB attenuator)	Values given in measurement protocol by DB6NT
144 MHz LNA miComm “L144QM” SN: #0120	NF = 0.13 dB Gain = 27.4 dB	NF = 0.21 dB Gain = 28.6 dB
432 MHz LNA miComm “L432QM” SN: #0128	NF = 0.09 dB Gain = 20.6 dB	NF = 0.33 dB Gain = 21.3 dB

Table 2: Comparing preamplifier measurement results.

5. Conclusions

In this paper the concept and realization of a simple precision automatic noise figure indicator (SPANFI) was presented. Mainly two ideas were realized which make this SPANFI different from former PANFI implementations:

- Broadband noise amplification and use of a (variable) RF bandpass filter instead of a more complex superhet principle with mixing to and filtering at an IF.
- Digital averaging for decreased standard deviation of the measured power instead of analogue averaging/integration by (analogue) low pass filtering.

These ideas make realization much more simpler. However further improvements are possible by use of a “larger” microcontroller:

- Calculation of logarithm instead of look-up table.
- Consideration of the noise figure of the SPANFI itself in noise figure calculation of the D.U.T. (cascaded noise figure calculation).
- More accurate gain calculation (see [5]).
- Temperature compensation if ambient temperature is not 290 K.
- Faster A-to-D conversion, thus higher measurement rate.

Instead of variable bandpass filtering a couple of bandpass filters for fixed centre frequencies of interest could be used. Also the use of higher input frequency log amplifiers, like the AD8313 [7], could be realized – but at a decreased dynamic range.

I would like to thank my friend Bodo, DL2FCN, for his critic encouragement and some nice measurement evenings in his shack and Heinz, DJ5FN, for some comparing measurements in the microwave laboratory at University of Applied Science in Darmstadt.

Literature:

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[8] www.linear.com: data sheet for 12 bit A/D converter LTC1860.
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Annex: source code of controller

```
'SPANFI: Simple Precision Automatic Noise Figure Indicator
'- ADC: LTC 1860
'- LCD: 2x16
'- switching of noise source at PB1
'- LED yellow at PD0 to show "on" state of noise generator
'- LED green at PD1 to show that calibration is finished
'

'*** v 0.2, date: 13.Feb.2006
'***
'*** DF1VH
'***
```

```
$regfile = "2313def.dat"                          'AT90S2313
$crystal = 10000000                               'Quarz: 10 MHz

Dim A As Integer                                  'temp var for ADC
Dim Resa As Integer                               'var for ADC result / noise figure in dB
Dim K As Byte                                     'run var / gain
Dim L As Integer


Dim P1n As Long                                   'power during calibration: noise generator connected to input of SPANFI
Dim P2f As Long                                   'power at output of D.U.T. with noise generator "off" at input
Dim P2n As Long                                   'power at output of D.U.T. with noise generator "on" at input
Dim N As Integer                                  'number of averaged values
Dim Y As Integer                                  'Y factor
Dim S As Byte                                     'shift value


Ddrd.0 = 1                                        ' port for yellow LED as output
Ddrd.1 = 1                                        ' port for green LED as output
Ddrd.2 = 0                                        ' ENR switch
Ddrd.3 = 1                                        ' port for ADC Clock
Ddrd.4 = 0                                        ' port for serial ADC result input
Ddrd.5 = 1                                        ' port for CS of ADC


Ddrb.1 = 1                                        ' port for noise generator switching


' alias names for adc control
Clk Alias Portd.3
Cs Alias Portd.5



Config Lcd = 16 * 2
Config Lcdpin = Pin , Db4 = Portb.4 , Db5 = Portb.5 , Db6 = Portb.6 , Db7 = Portb.7 , E = Portb.3 , Rs = Portb.2
Initlcd
Cls
Cursor Off

Main:
'intro
Cls
Lcd "**** DF1VH ****"
Lowerline
Lcd "* SPANFI v0.2 *"
Waitms 1000


' 0. init LCD and check of ENR switch
Cls

If Pind.2 = 0 Then
 Lcd "ENR = 15.53 dB"
 Else
 Lcd "ENR =  5.93 dB"
End If


' 1. Calibration: only used for gain measurement of D.U.T.
'    therefore: power P1n for noise generator "on" as average of 16384 instantenuous values;
Lowerline
Lcd "CAL ..."

Portb.1 = 1
Portd.0 = 1
P1n = 0
For L = 1 To 16384
 Gosub Adc
 P1n = P1n + Resa
Next
'dividing result by 16384 by shift right operation
Shift P1n , Right , 14

' show that calibration is finished by switching on green LED
Portd.1 = 1
```

```
'2. repeated measurement in loop
Do

Portb.1 = 0
Portd.0 = 0
P2f = 0

' if wide nf range (and ENR1) then averaging over 4096 values, narrow range (and ENR2) averaging over 8192 instanteuous values
N = 8192
S = 13
If Pind.2 = 0 Then
N = 4096
S = 12
End If

'2.1 (average) power p2f for noise generator "off"
For L = 1 To N
 Gosub Adc
 P2f = P2f + Resa
Next
'dividing result by Sv by shift right operation
Shift P2f , Right , S

'2.2 (average) power p2n for noise generator "on"; yellow LED on/[off] when noise generator is on/[off]!
Portb.1 = 1
Portd.0 = 1
P2n = 0
For L = 1 To N
 Gosub Adc
 P2n = P2n + Resa
Next
'dividing result by Sv by shift right operation
Shift P2n , Right , S

'2.3 difference of log values is Y factor: Y = p2n - p2f
Y = P2n - P2f


'2.4 evaluate look up table for NF = ENR - 10*log10(Y)

Cls

If Pind.2 = 0 Then
' in case of enr=15.5 dB stepsize of y value is reduced to 0.16 dB
 Shift Y , Right , 2

'Y is now considered as index of look up table
 Y = Y - 7
'look into table Nf1 with index Y
 K = Lookup(y , Nf1)

 If Y < 0 Then
  Lcd "NF =  ??       "

 End If

 If Y > 94 Then
  Lcd "NF =  ??       "
 Else
' diplay NF if valid value within look up table
  Lcd "NF [0.1dB]=  " ; K
 End If

 Else

' in case of enr=5.93 dB
 Y = Y - 129
'look into table NF2 with index Y
 K = Lookup(y , Nf2)

 If Y < 0 Then
  Lcd "NF =  ??       "
 End If

 If Y > 47 Then
  Lcd "NF =  ??       "
 Else
' diplay NF if valid value within look up table
  Lcd "NF[0.01dB]= " ; K
 End If


End If


'2.5 calculate and show gain
L = P2n - P1n
Lowerline

Shift L , Left , 2
'show gain value
Lcd "G [0.01dB]=" ; L


' 3. Loop for continuous measurement of Gain and NF
Loop


'A-to-D conversion subroutine follows:

Adc:
 Set Cs                                    'start of adc with cs=high
 Reset Clk
 Reset Cs                                   'select chip
 A = 0
 Resa = 0
 For K = 1 To 12                                'read 12 bits from adc
  Resa = Resa * 2                               'shift one bit to left
  Gosub Pulse                                  'send clock pulse
  Resa = Resa + A                                'grab last bit
  If Pind.4 = 1 Then
  A = 1
  Else
  A = 0
  End If
 Next
 Set Cs
 Return


Pulse:                                     'clock frequency as fast as possible...
 Set Clk

 Reset Clk

 Return

'look up tables to translate Y factor into NF for two different ENR values

'ENR = 15.53 dB; Y measured between 0.4166627 dB and 15.649888 dB (7...100) where step size 0.1565625 dB
'here: NF*10 values in dB for this Y range when ENR = 15.53 dB assumed
Nf1:
Data 210 , 203 , 197 , 192 , 187 , 182
Data 178 , 174 , 170 , 166 , 163 , 159 , 156 , 153 , 150 , 147
Data 144 , 141 , 139 , 136 , 134 , 131 , 129 , 126 , 124 , 122
Data 119 , 117 , 115 , 113 , 111 , 109 , 106 , 104 , 102 , 100
Data 98 , 96 , 94 , 92 , 91 , 89 , 87 , 85 , 83 , 81
Data 79 , 77 , 76 , 74 , 72 , 70 , 68 , 67 , 65 , 63
Data 61 , 60 , 58 , 56 , 54 , 53 , 51 , 49 , 48 , 46
Data 44 , 43 , 41 , 39 , 38 , 36 , 34 , 33 , 31 , 29
Data 28 , 26 , 24 , 23 , 21 , 19 , 18 , 16 , 14 , 13
Data 11 , 10 , 8 , 6 , 5 , 3 , 2 , 0

'ENR = 5.93 dB (15.53 dB ENR source + 9.6 dB attenuator); Y measured between 5.0211423 dB and 6.9173719 dB (129...177) where step size 0.03914 dB
'here: NF*100 values in dB for this Y range when ENR = 5.93 dB assumed
Nf2:
Data 251 , 245 , 240 , 234 , 228 , 223 , 217 , 212 , 206 , 201
Data 195 , 190 , 184 , 179 , 173 , 168 , 163 , 157 , 152 , 147
Data 141 , 136 , 131 , 125 , 120 , 115 , 110 , 105 , 99 , 94
Data 89 , 84 , 79 , 74 , 69 , 64 , 58 , 53 , 48 , 43
Data 38 , 33 , 28 , 23 , 18 , 13 , 9 , 4
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